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Television [1]

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SYNOPSIS: The chief problems presented in the accomplishment of television are discussed. These are: the resolution of the scene into a series of electrical signals of adequate intensity for transmission; the provision of a transmission channel capable of transmitting a wide band of frequencies without distortion; means for utilizing the transmitted signals to re-create the image in a form suitable for viewing by one or more observers; arrangements for the accurate synchronization of the apparatus at the two ends of the transmission channel.

INTRODUCTION

THIS paper is to serve as an introduction to the group of papers following, which describe the apparatus and methods used in the recent experimental demonstration of television over communication channels of the Bell System. In that demonstration television was shown both by wire and by radio. The wire demonstration consisted in the transmission of images from Washington, D. C., to the auditorium of the Bell Telephone Laboratories in New York, a distance of over 250 miles by wire. In the radio demonstration, images were transmitted from the Bell Laboratories experimental station at Whippany, New Jersey, to New York City, a distance of 22 miles. Reception was by two forms of apparatus. In one, a small image approximately 2 in. by 2½ in. was produced, suitable for viewing by a single person, in the other a large image, approximately 2 ft. by 2½ ft., was produced, for viewing by an audience of considerable size. The smaller form of apparatus was primarily intended as an adjunct to the telephone, and by its means individuals in New York were enabled to see their friends in Washington with whom they carried on telephone conversations. The larger form of receiving apparatus was designed to serve as a visual adjunct to a public address system. Images of speakers in Washington addressing remarks intended for an entire audience, and of singers and other entertainers at Whippany, were seen by its use, simultaneously with the reproduction of their voices by loud speaking equipment.

[1] Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20–24, 1927.

Characteristic Problems of Television

The problem of television in its broad outlines is that of converting light signals into electrical signals, transmitting these signals to a distance, and then converting the electrical signals back into light signals. Given means for accomplishing these three essential tasks, the problem becomes that of developing these means to the requisite degree of sensitiveness, speed, efficiency, and accuracy, in order to re-create a changing scene at a distant point, without appreciable lapse of time, in a form satisfactory to the eye.

A convenient starting point for the discussion of television is the human eye itself. In this an image is formed upon the retina, a sensitive screen, consisting of a multitude of individual light-sensitive elements. Each of these elements is the termination of a nerve fibre which goes directly to the brain, the entire group of many million fibres constituting the optic nerve. A theoretically possible television system could be made by copying the eye. Thus a large number of photosensitive elements could be connected each with an individual transmission channel leading to a distant point, and signals could be sent simultaneously from each of the sensitive elements to be simultaneously used for the re-creation of the image at the distant point. The number of wires or other communication channels demanded in a television system of this sort would be impractically large. For practical purposes, reduction of the number of transmission channels is made possible by the fact that, while in vision all parts of the image on the retina are simultaneously and continuously acting to send nerve impulses, the inertia of the visual system is such that a sensation of continuity is obtained from discontinuous signals, provided these succeed each other rapidly enough. Due to the phenomenon of persistence of vision, it is immaterial to the eye whether the whole view be presented simultaneously or whether its various elements be viewed in succession, provided the entire image be traversed in a sufficiently brief interval, which for purposes of discussion may be taken as 1/16th of a second or less.[2] We thus have available in television the same artifice which is used in the much less exacting problem of transmission of pictures over a telephone line, that is, of *scanning*, or running over the elements of the image in sequence, instead of endeavoring to transmit all of the elementary signals simultaneously. The development of a television system therefore

[2] This figure of 1/16th of a second, commonly quoted in discussions of this sort, is a convenient one, although the frequency of image repetition necessary to extinguish "flicker" is actually proportional to the logarithm of the field brightness. A somewhat higher rate of image repetition was used in the final television apparatus.

necessitates, at an early stage, the design of some scanning system by which the image to be transmitted may be broken up into sequences of signals. In the simplest case, where one transmission channel is to be used, the whole image will be resolved into a single series of signals; if more than one transmission channel is to be utilized, the resolution may, by parallel scanning schemes, or their equivalent, be broken up into several series for simultaneous transmission.

Like the eye, an artificial television system must have some light-sensitive element or elements by means of which the light from the object shall produce signals of the sort which can be transmitted by the transmission system to be used. For a television system to operate over electrical transmission lines this means some photoelectric device. It is obvious that this photoelectric device must be extremely rapid in its response, since the number of elements of any image to be transmitted must be some large multiple of the fundamental image repetition frequency, that is 16 per second. The response should, of course, be proportional to the intensity of the light, and finally, the device must be sufficiently sensitive so that it will give an electrical signal of manageable size with the amount of light available through the scanning system. This latter requirement, that of sensitiveness, is one which, it was realized, from studies made with our earlier apparatus for the transmission of still pictures over wires,[3] would be extremely difficult to meet. In the picture transmission system a very intense beam of light from a small aperture is projected through a transparent film and on to a photoelectric cell. In practical television, the system must be arranged to handle light reflected from a natural object, under an illumination which would not be harmful or uncomfortable to a human being. Actual experiment showed that the greatest amount of light which could be collected from an image, formed by a large aperture photographic lens on the small scanning aperture of the picture transmission apparatus, was less by a factor of several thousand times than the light projected through it for still picture transmission purposes. Assuming the same kind of photoelectric cell to be used, the additional amplification required over that used in the picture transmission system, taking into account also the higher speed of response demanded, would bring us at once into the region where amplifier tube noise and other sources of interference would seriously affect the result. This indicated clearly that some more efficient method of gathering light from the object than the commonly assumed one of image formation by a

[3] "Transmission of Pictures over Telephone Lines," Ives, Horton, Parker and Clark. *Bell System Technical Journal*, Vol. IV, No. 2, April, 1925.

lens was required, unless some much more sensitive type of photoelectric cell should be found.

Assuming that means could be developed for producing an electrical signal proportional to the intensity of the light, of sufficient quickness to follow a rapid scanning device, and of sufficient strength either as directly delivered from a photosensitive device or as amplified, the next problem is that of its transmission over an electrical communication system. We may quickly arrive at an understanding of certain of the transmission problems by reviewing the requirements for the transmission of photographs. In the system of still picture transmission now in use by the American Telephone & Telegraph Company, a picture 5 in. by 7 in. in size, divided into the equivalent of 10,000 elements per square inch or 350,000 elements, is transmitted in approximately seven minutes. This requires the transmission of a frequency band of about 400 cycles per second on each side of the carrier frequency. If we plan, in the transmission of television, to transmit images of the same fineness of grain, it would mean that what is now transmitted in seven minutes would have to be transmitted in a 16th of a second, which in turn means that the transmission frequency range would have to be nearly 7000 times as great. That is, a band approximately 3,000,000 cycles wide would be required. Bearing in mind that wire circuits are ordinarily not designed to utilize frequencies higher than 40,000 cycles per second, and that with radio systems uniform transmission of wide signal bands becomes extremely difficult, it is seen at once that either an image of considerably less detail than that which we have been considering must suffice, or else some means for splitting up the image so that it may be sent by a large number of channels is indicated.

A further theoretical requirement must also be given consideration. This is that the complete television signal will consist of all frequencies up to the highest above discussed, and down to zero, that is, an essential part of the signal is the direct current component, furnished by those parts of the scene which do not change. The problem of handling the very low frequency components, presents difficulties both in the vacuum tube amplifier system adjacent to the photosensitive device, and in ordinarily available transmission channels.

In any case certain fundamental transmission requirements must be met. These are that the attenuation of the signals must be uniform over the whole frequency range and that the speed of transmission of all frequencies must be the same. Also, as in the transmission of sound signals, the amount of interference or noise must be kept down sufficiently not to impair the quality of the signal or picture.

Assuming the undistorted transmission of the signals to a distant point, the next fundamental problem of television is the reconstruction of the image, or the translation of the electrical signal back into light of varying intensity. Just as at the sending end we have seen that the production of a useful electrical signal with the amount of light available from a naturally illuminated object is a major problem, so at the receiving end the converse problem, that of securing an adequately bright light from the electrical signal, presents great difficulty. The nature of the problem may be understood by assuming that it is to be done by projecting the received image on a screen similar to an optical lantern projection screen. If the spot of light which is to build up this image scans the whole area in the same way that the object is scanned, we find that the amount of light which can be concentrated into a small elementary spot will, when distributed by the scanning operation over the whole screen, reduce the brightness of the screen in the ratio of the relative areas of the elementary spot and the whole screen. The amount of this reduction will, of course, depend upon the number of elements into which the picture is divided, but will in any event be a factor of several thousand times. It is doubtful whether any light source exists of sufficient intensity such that an image projected by it can be spread out by a scanning operation over a large screen and give an average screen brightness which would be at all adequate. It is possible to imagine optical systems by which such a thing as the crater of an arc could be projected upon the screen, but the motion of this image and its variation in intensity would involve the extremely rapid motion of lenses, mirrors and apertures of a size such as to render the operation mechanically impracticable. It appears from these considerations that the only promising means of reconstructing the image would be those in which a light source, whose intensity can be controlled with great rapidity, is directly viewed.

Another element of a television system upon whose solution success depends as much as any other is that of synchronization; the reconstruction of the image, postulated in the last paragraph, is only possible if the reconstructed elements fall in exactly the right positions at the right times, to correspond with the signals as generated at the analyzing end. The criterion for satisfactory synchronization will be expressed in terms of variation from identity of speed by figures which will depend on the fineness of grain of the image which it is planned to send. No element of the image must, of course, be out of place by a considerable fraction of the size of the element.

General Outline of Means Employed in the Present Television System

It has been pointed out above that if the goal which we set in television is the transmission of extended scenes, with a large amount of detail and hence made up of an exceedingly large number of elementary areas, we meet with the necessity for transmission channels of a character which are not now available. In the present development it was decided at the start to restrict our experiments to a size and grain of picture which, if the scanning and re-creating means were developed, would be capable of transmission over practical transmission channels, either wire or radio. This restriction fortunately leaves us with the possibility of meeting what was felt to be the typical problem of a Telephone Company, namely, the transmission of a human face in a television system used as an adjunct to a telephone system. Taking, as a criterion of acceptable quality, reproduction by the halftone engraving process, it is known that the human face can be satisfactorily reproduced by a 50-line screen. Assuming equal definition in both directions, 50 lines means 2500 elementary areas in all. 2500 elements transmitted in 1/16 second is 40,000 elements per second. The frequency range necessary to transmit this number of elements per second with a fidelity satisfactory for television cannot be calculated with assurance in advance. An approximate value can however be arrived at from a study of the results obtained in still picture transmission. In pictures transmitted by the system already referred to, individual faces contained in a square space ½ inch on a side are quite recognizable.[4] Taking the ratio of this area to the area of the whole picture, and using the frequency range figure already deduced, for a complete 5 in. by 7 in. picture, it appears that a band of 20,000 cycles would be sufficient to transmit such an image in 1/16 second.[5] These considerations led to the choice of a 50-line (2500-element) image as one which would be both satisfactory as to detail rendering, for our purposes, and as calling for frequency transmission requirements sufficiently low to give a good margin of safety in existing single communication channels.

As a method of scanning, the method which is probably mechanically simplest, namely, that of rotating disks with spirally arranged holes, proposed by Plotnow[6] in 1884, was chosen. In accordance with the

[4] Cf. Fig. 18 of the paper referred to (Reference 2).

[5] A factor which this analogy does not cover is that if the image is moving so that it falls on several discrete scanning elements in rapid succession a very material apparent increase in the fineness of the image structure results. This effect is similar to that by which the relatively coarse-grained individual images in a motion picture film fuse to give smooth appearing pictures.

[6] Plotnow, D. R. P. 30105, 6.1, 1884.

choice of grain above indicated, the disks were perforated with 50 apertures.

For the second element of the problem, the light-sensitive means, the alkali metal photoelectric cell was chosen as possessing the qualities of proportionality of response and quickness of reaction. The currents produced by it are at best quite small, but they lend themselves to the process of amplification by the three-electrode vacuum tube amplifier.

The problem of securing a large enough signal, which is intimately associated with that of securing enough light from the object, was, in our development work, postponed in the earlier stages, our first experimental work having been done by concentrating light through photographic transparencies.[7] The solution of the problem of securing adequate light was subsequently attained by reversing the light path and projecting a narrow beam of light through the scanning disk upon the object. By this means only the element of the object which was being scanned was illuminated at any one time, thereby reducing the average illumination enormously, and the problem of increasing the signal strength could be attacked by increasing the amount of photosensitive surface as well as by increasing the brightness of the scanning light.[8]

The problem of amplifying the photoelectric currents to sufficient value for transmission was solved by a practical compromise which at the same time met one of the transmission difficulties. This compromise consisted in amplifying and transmitting only the fluctuating or alternating current components of the signal, leaving the direct current component, which determines the general tone value of the image, for empirical reintroduction at the receiving end. By this scheme, stable amplifier constructions were made available, and the transmission channels, particularly the wire channels, could be utilized in their normal working form.

At the receiving end, the problem of securing a sufficiently bright image was solved, as indicated earlier, by the use of self-luminous surfaces of much higher intrinsic brightness than it is possible to secure by illumination of a surface by any light source which can be rapidly controlled as to its intensity. The self-luminous surfaces

[7] As one step in the development work moving picture film, projected by a commercial projector in synchronism with the scanning disks, was successfully transmitted.

[8] A still further advantage is obtained by limiting the scanning light to the region of the spectrum to which the photoelectric cells are sensitive (blue and violet). This is unnecessary where one-way transmission only is used but is of value where in two-way transmission a transmitted image is to be viewed by a person being scanned.

employed were glow lamps containing neon gas, the brightness of which changes with sufficient rapidity to follow the incoming signals.

The problem of synchronization was postponed in our earlier development work by mounting the scanning and receiving disks upon the same axle. It was later solved for the demonstration apparatus by the utilization of synchronous motors controlled by two frequencies, a low frequency, that of the image repetition period, and a high frequency, chosen of such a value that the fraction of the cycle through which transient phase displacements occurred amounted in angular displacement to less than half the angular extent of a single disk aperture. The synchronization control therefore called for the transmission of additional currents for synchronization purposes over and above the picture current.

In order to transmit and synchronize the image signals it is necessary to transmit three different frequency bands, one for the image, and two for the high and low frequency synchronization controls. In the demonstration of April 7, 1927, the images were sent in the wire demonstration over a high quality open wire line. The synchronization control was sent over two separate carrier channels of a second telephone line. In addition to these lines, another line was used for conveying the telephone conversation. In the radio demonstration two different wave-lengths were used respectively for the image signals and for the synchronization signals which were, as in the wire demonstration, carried on two different carrier frequencies. A third channel was used for the voice. In the case of both wire and radio transmission, it is quite possible to put all of the different signals upon the same transmission channel, using different carrier frequencies.

It will aid toward a clear understanding of the reasons for the success of the system of television described in the following papers if we summarize at this point the chief novel features to which that success is due. They may be listed as follows:

1. Choice of image size and structure such that the resultant signals fall within the transmission frequency range of available transmission channels.[9]
2. Scanning by means of a projected moving beam of light.
3. Transmission only of alternating current components of image.
4. Use of self-luminous surfaces of high intrinsic brilliancy for reconstruction of the image.
5. High frequency synchronization.

[9] As the succeeding papers show, the margin between the frequency range required by the scanning apparatus and that which could be made available was quite liberal. It appears in the light of our experience that apparatus with 60 or 70 scanning holes instead of 50 might be used with the transmission facilities which were at our disposal.

Applications and Future Developments

It is not easy at this early date to predict with any confidence what will be the first or the chief uses for television, or the exact lines that future development may take. It must be clearly understood that television will always be a more expensive service than telephony, for the fundamental reason that it demands many times the transmission channel capacity necessary for voice transmission. This expense will inevitably increase in proportion to the size and quality of the transmitted image.

The kinds of service which are naturally thought of upon consideration of the services now rendered in connection with sound transmission are: first, service from individual to individual, parallel in character to telephone service, and as an adjunct thereto; second, public address service, by which the face of a speaker at a distant point could be viewed by an audience while his voice was transmitted by loud speaker; third, the broadcasting of scenic events of public interest, such as athletic contests, theatrical performances and the like.

The first two types of service just mentioned lie within the range of physical practicability, with apparatus of the general type already developed. The third type, because of the uncontrolled conditions of illumination, and the much finer picture structure which would be necessary for satisfactory results, will require a very considerable advance in the sensitiveness and the efficiency of the apparatus, to say nothing of the greatly increased transmission facilities. For all three types of service, wire or radio transmission channels could be utilized, for while the problems incident to securing distortionless transmission over wide frequency bands, or multiple transmission channels, are different in detail in the two cases, they appear to be equally capable of solution by either means. However, the very serious degradation of image quality produced by the fading phenomena characteristic of radio indicates the practical restriction of radio television to fields where the much more reliable wire facilities are not available.